Renewal of Multi-Scale Model-Driven Sampling with Autonomous Systems at a National Littoral Laboratory: Turbulence Characterization with an AUV

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LONG-TERM GOALS

The overall goal of this research is to utilize turbulence measurements obtained from small Autonomous Underwater Vehicle (AUV) based sensors to improve mixing parameterizations in the data-assimilative modeling components of the LEO coastal prediction network applied to coastal upwelling. The rational for this research is that the lack of observations of vertical mixing rates imposes a severe limitation on our understanding of mixing processes in coastal waters, as well as on the development of models for them. A necessary step toward understanding these mechanisms is to directly observe spatial and temporal variations in turbulent mixing in and near upwelling events.

OBJECTIVES

The specific objectives of this research is to utilize turbulence measurements to investigate the role of vertical mixing processes on a variety of Continental Shelf physical processes, with the emphasis on upwelling and fronts. The specific scientific questions addressed are related to determining the horizontal spatial scale of mixing events, and relating their distribution to larger scale structures and dynamics in synergistic observations and modeling studies.

APPROACH

The work focuses on summertime upwellimg along the New Jersey coast in response to southerly winds, and topography (Glenn et al, 1996). Upwelling centers can be responsible for low bottom dissolved oxygen, disrupting fisheries. The AUV is deployed in the evolving and fully developed upwelling process. Turbulence closure models in SCRUM include the Mellor-Yamada level 2.5 (Mellor and Yamada, 1974) and the KPP, which use diffusivities and fluxes that are largely untested on the shelf. Model generated eddy diffusivity fields target hot spots for AUV validation surveys.

The microstructure instrument (Levine et al, 1999) is a REMUS AUV with: 1) shear sensors for turbulent kinetic energy dissipation rates, 2) a fast thermistor for thermal dissipation rates, and 3) an Acoustic Doppler Velocimeter for 3D velocity. REMUS has two CTDs, and an up/down looking ADCP. The shear probe data are processed to remove noise associated with vehicle vibrations, using

accelerometers, and the techniques of Levine and Lueck (1999). In addition to microstructure, these sensors provide stratification and finescale shear, enabling estimation of Richardson number, eddy diffusivity (Gargett and Moum, 1995), eddy viscosity (truncated TKE equation), fluxes (correlation technique) and turbulent kinetic energy.

For the LEO network, the modeling program in the Middle Atlantic Bight includes SCRUM, a coastal circulation model (Song and Haidvogel, 1994), with additional features for prediction of sediment transport and biological/optics. The observational nodes (von Alt and Grassle, 1992) are an autonomous oceanographic sampling network (Curtin et al., 1993), which includes real time data feeds for moored, profiling, and AUV-based data acquisition for the modeling. Satellite data, local meteorology, and conventional shipboard and moored data are available near the LEO site. An unresolved issue in the use of the SCRUM model is the choice of subgrid turbulence closure schemes, i.e., Mellor and Yamada, 1974, or Large et al., 1994.

WORK COMPLETED

The AUV-based turbulence estimates are utilized to characterize subgrid scale processes in the SCRUM model and compare turbulence closure approaches. Field experiments were conducted in the LEO-15 region off New Jersey (Glenn et al, 1996), to examine mixing processes associated with wind-driven upwelling. During July 1998, using model-based adaptive sampling, the AUV was deployed along trajectories through components of the fully developed upwelling region, including the upwelling gyre center and offshore leg. During July 1999, sampling was done in the emerging upwelling circulation, including the detached offshore "jet". For the final model prediction cycle, the data derived eddy viscosity in the upstream pipe was utilized as the inshore maximum value for SCRUM.
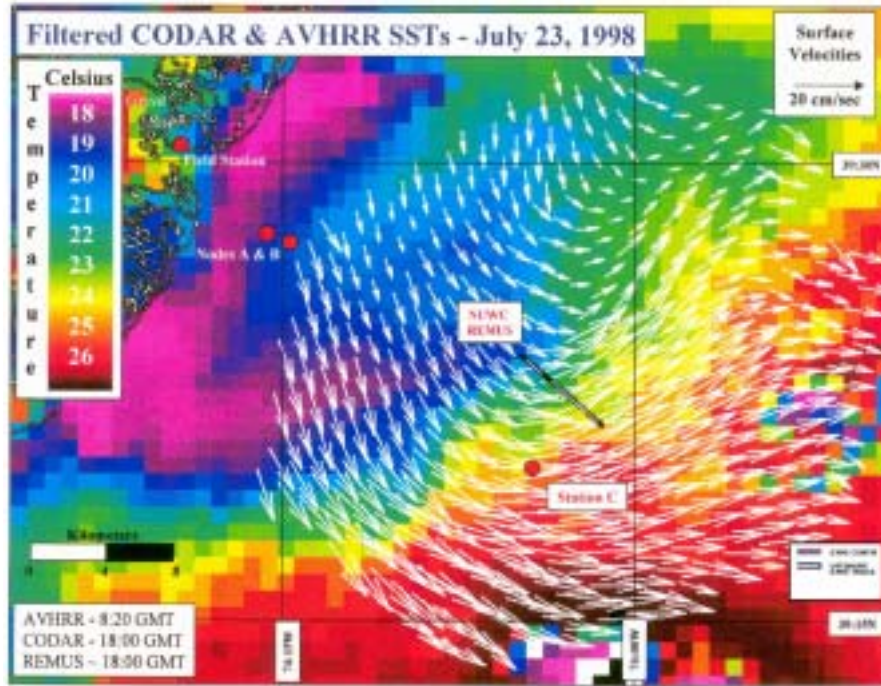
RESULTS

During July 1998, using SCRUM model-based adaptive sampling, the AUV was deployed along a trajectory through components of the Leo-15 upwelling region, near 39° 22.5'N, 74° 3.5' W, including the upwelling gyre and offshore jet (Fig. 1). These measurements were made synoptically with those from other platforms which characterize larger scale structures on the nearby continental shelf. Model predictions which include assimilated data from the wide variety of sampling platforms is also available for comparison.

For the proposal renewal, the turbulence data were re-analyzed, using new techniques developed for subsequent experiments. In particular, a partial coherence technique is now utilized to futher remove platform vibrations from the shear probe data, using thee three orthogonal accelerometers located near these probes. Also, a field calibration of the two CTDs is used to improve gradient calculations (Levine and Lueck, 2001).

Results indicate that the modified REMUS AUV was a viable platform for turbulence data acquisition in the coastal ocean. Data obtained from the vertical and transverse shear probes have been processed to remove noise associated with vehicle vibrations. This process is done using data from accelerometers located in the probe pressure case directly behind the probe mounts. The autospectra compare well to the Nasmyth "universal spectrum" (Oakey, 1982) for the appropriate dissipation rate and viscosity out to wavenumbers close to the physical size of the sensing tip of the shear probes.

Horizontal profiles of turbulence data for segments in the upwelling gyre center and offshore leg are include vertical velocity shear (obtained from a shear probe), temperature microstructure (obtained from finite differencing the filtered thermistor data), density gradient (from the two vertically oriented CTDs), and finescale vertical current shear components (from the upward and downward looking ADCP bin data).

Fig 1. The Turbulence AUV data track through the upwelling gyre in the LEO region off New Jersey, July 1998.

From these turbulence data, profiles of mixing parameters can be obtained. Results show that the dissipation rate was estimated to be 2-3 x 10^{-7} W/kg in the gyre center, and 3 x 10^{-7} to 2 x 10^{-6} W/kg in the offshore gyre track. Correspondingly, the calculated eddy diffusivities (eddy viscosities) were approximately 1 x 10^{-5} - 4 x 10^{-4} (4 x 10^{-4} - 2 x 10^{-3}) in the gyre center, and 4 x 10^{-5} to 1 x 10^{-3} (3 x 10^{-4} - 2 x 10^{-3}) n the offshore gyre track. The Richardson number profiles were calculated to be of order 10^{0} to 10^{1} in the gyre center, and of order 10^{0} to 10^{-1} in the offshore gyre track. The trajectory through the pre-upwelling detached jet from July 1999, near 39° 26.3'N, 74° 13.7' W is shown in Fig. 7. Turbulence parameters for this track show relatively large values of finescale shear. The dissipation rate was estimated to be 5 x 10^{-9} to 2 x 10^{-8} W/kg in the jet. The trajectory through the pre-upwelling detached jet from July 1999, near 39° 26.3'N, 74° 13.7' W is shown in Fig. 7. Turbulence parameters for this track show relatively large values of finescale shear. The dissipation rate was estimated to be 5 x 10^{-9} to 2 x 10^{-8} W/kg in the jet.

One example of a comparison of mixing processes can be performed by examining the data sets distribution on a plot where the buoyancy Reynolds number

$Re_b = \varepsilon / \nu N^2$

is plotted on the x axis, and the Froude number

$$Fr = (1/Ri)^{1/2}$$

is plotted on the y axis. The corresponding groupings of the datasets can be evaluated in terms of their presence in three regimes indicative of mixing process characterization: The buoyancy dominated regime $Re_b < 20$, the region where $20 < Re_b < 200$ in which buoyancy is still important and isotropy may not hold, and for $Re_b > 200$ where isotropy holds (Gargett et al, 1994).

This comparison of mixing processes (Fig. 2) indicates that the 1998 onshore gyre LEO data was primarily in the intermediate region where buoyancy is still important, and the Froude numbers are low
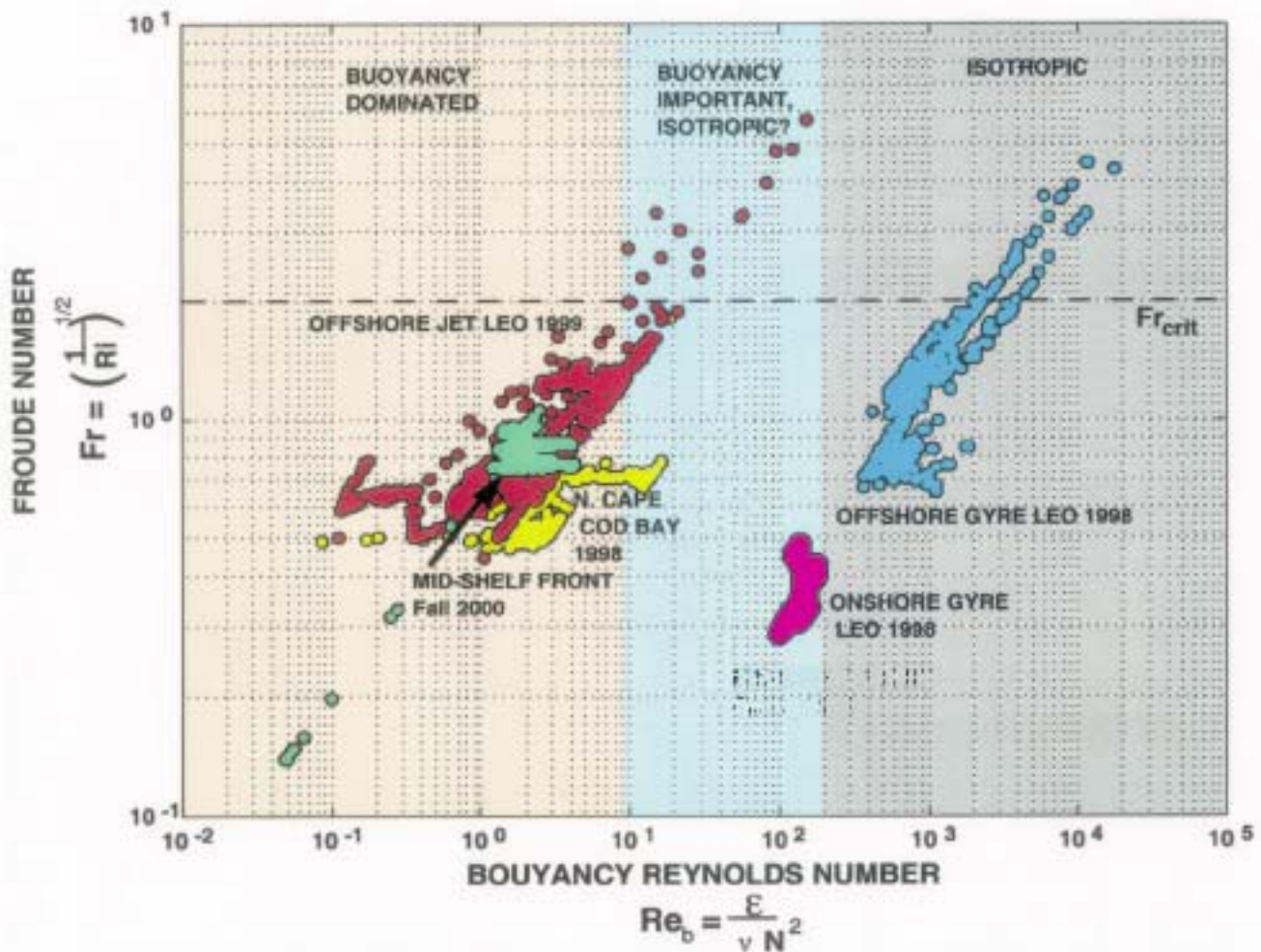
Fig 2. Mixing process comparison
[The data fall in three turbulent regimes]

(below the critical Froude number, 2). In contrast the 1998 offshore gyre LEO data was located in the isotropic region, with higher Froude numbers than the onshore data, including some above 2. In 1999, the detached jet at LEO data was in the buoyancy dominated and intermediate regions, with some Froude numbers greater than 2. The approximate 1/2 slope of the majority of points in both the 1998

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and 1999 LEO upwelling data on this log-log plot is consistent with a constant eddy diffusivity, whose magnitude changes with different intercepts.

IMPACT/APPLICATIONS

The AUV-based turbulence measurements provide a unique horizontal profiling view of the variability of the mixing environment that cannot be obtained by more conventionally sampling measurements, and this approach can be further exploited in yo-yoed horizontal sections. These techniques are invaluable in frontal process studies utilizing the SCRUM model.

TRANSITIONS

This research demonstrates an Autonomous Ocean Sampling Network (AOSN) in the context of an Integrated Coastal Observing System in a region with tactically significant features. This is a prototype demonstration, which can be extrapolated to an environmental description of the Battlespace for superiority in ASW and MCM.

RELATED PROJECTS

My AUV-based turbulence measurement system has also being utilized in NOPP/ONR FRONT studies led by the University of Connecticut.

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